

15 MAR 1932

CIRCULAR NO 195

NOVEMBER, 1931

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

TESTS OF SPRAY IRRIGATION EQUIPMENT

By F. E. STAEBNER, *Associate Drainage Engineer, Bureau of Agricultural Engineering*

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INTRODUCTION

Recently spray-irrigation equipment, designed for the irrigation of general farm crops, has been developed in Germany. The question arose as to whether it possessed advantages for use under American conditions and how it compared with American spray-irrigation equipment. Accordingly, tests of typical German and American equipment were made during the summer of 1928. The primary object of these tests was to determine the uniformity of the water distribution over the surface.

A plot of ground on the Arlington Experiment Farm at Rosslyn, Va., was selected where water under pressure heads up to approximately 58 pounds per square inch was available. The spot was more or less sheltered from the wind, being low as compared with most of the surrounding area. The most pronounced wind barrier was the elevated embankment of an abandoned canal adjacent to the field on the east. This embankment was broken on the southeast by a cut for a road. An orchard on rising ground immediately to the north and a considerable knoll somewhat more distant to the southwest further varied the topography. These local variations seemed to have very disturbing effects when the wind was in certain directions.

Two additional nozzles were tested in the spring of 1931. Water under pressure was then available at a more suitable site on the same farm, and it is believed that in that location wind effects were minimized.

GENERAL PROCEDURE

To determine the distribution of water as sprayed out by the nozzles, receptacles were placed at suitable locations over the area wetted. For this purpose 13 rain gages and 100 ordinary tin cans were used. The rain gages were of the standard Weather Bureau type, and the tin cans had approximately a diameter of 6 inches and a height of 13 inches. Two or three different arrangements were followed in placing the receptacles, depending upon the type of equipment being

tested. For the tests with the German nozzles and with most of the American circular-spray nozzles, the cans were placed along the diameters and diagonals of

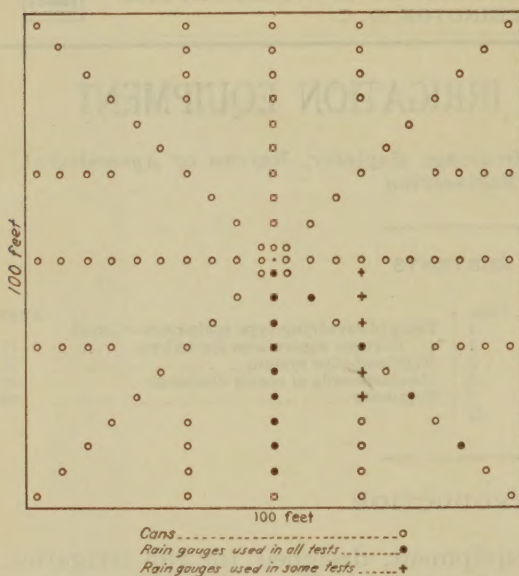


FIGURE 1.—Layout of cans for tests of circular-spray nozzles

as shown in Figure 2. The tops of the receptacles were all brought to the same elevation.

As the ground surface had considerable slope this meant that some cans were entirely above ground and some were to a large extent sunk into it. If it was necessary to sink the cans much below the natural surface enough earth was scooped away so that the rim of the can stood at least $1\frac{1}{2}$ inches above the immediately surrounding earth, and occupied the center of a broad, dishlike depression. The rain gages were weighted against flotation by draintile, one whole length and one short length of 4-inch tile and a like amount of 6-inch tile being placed in each. Flo-

tation of deeply embedded cans was prevented by a wire running through each can about $1\frac{1}{2}$ inches below the open end, the ends of the wire being fastened to stakes 4 to 6 inches from the can.

Ordinarily tests were run for periods of one-half hour although 1 test was run for only 20 minutes, several were run for 1 hour,

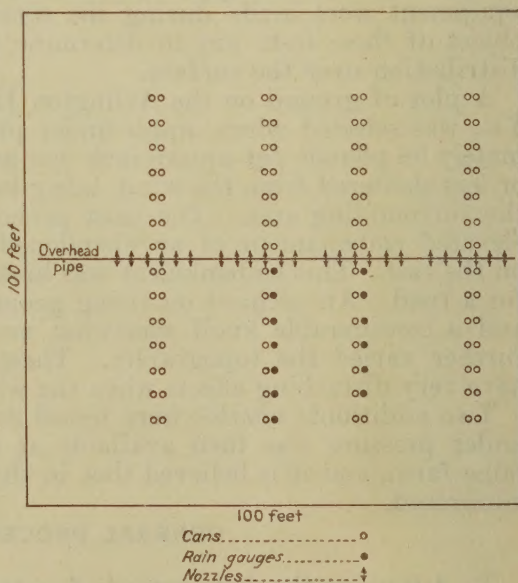


FIGURE 2.—Layout of cans for overhead-spray system

and a few were run for intermediate lengths of time. For purposes of comparison the quantities of water caught were reduced to the equivalent of 30 minutes' operation.

To make sure that there were no great discrepancies between the depth of water caught by the cans and that caught by the rain gages, the four corner cans, Nos. 1, 2, 3, and 4 were, for several tests, removed from their position and arranged around a rain gage. When thus used can No. 1 was always placed on the side of the rain gage nearest the center of the field and can No. 4 on the opposite side. Cans Nos. 2 and 3 were placed on the sides of the rain gage at right angles to the line connecting No. 1 and No. 4. Of these two, can No. 3 was always on the easterly side of the rain gage. The results of these tests are shown in Table 1.

TABLE 1.—*Depth of water caught in the receptacles*

Can No.	Depth of water caught in—						
	Test No. 11	Test No. 13	Test No. 18	Test No. 21	Test No. 22	Test No. 27	Test No. 29
	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>
1	0.025	0.25	0.10	0.06	0.07	0.08	0.04
2	.025	.24	.05	.05	.05	.08	.04
Rain gage	.020	.25	.05	.04	.04	.12	.04
3	.025	.24	.08	.05	.05	.07	.04
4	.025	.23	.02	.03	.04	.07	.04

At the beginning and end of each test the readings of a water meter were taken to determine the quantity of water discharged by the nozzle. For this a 2-inch meter, reading in cubic feet, was used for the tests of the circular-spray nozzles investigated in 1928. This meter was calibrated by the United States Bureau of Standards following the tests and the readings corrected to agree with the calibration curve. In the tests of the overhead-pipe equipment four different types of nozzles were used simultaneously. Nevertheless, a 1-inch meter was inserted in the supply pipe, and the records obtained from it were used to check the discharge curve for these nozzles, as is subsequently explained.

At various intervals during the tests the water pressure, as indicated by standard commercial pressure or altitude gauges, was read and recorded. Two new pressure gauges were used, and no correction was intended until, in the midst of the tests, a difference of nearly 2 pounds in the reading of these gauges in the same location was discovered. Upon completion of the tests these gauges were calibrated by the United States Bureau of Standards. The corrected gauge readings were used after the discrepancy was discovered. A correction for elevation was made in every instance where this factor was important.

As the intensity and direction of wind movement are of considerable importance, observations of wind movement were made. This was done by mounting a Biram-type anemometer on an improvised weather vane. The readings of the anemometer were taken just after starting and just before stopping a test, and from the readings thus obtained the rate of wind movement in miles per hour was determined. Wind direction was determined by frequent observa-

tions of the weather vane during the course of each test, and an average wind direction for the test estimated at the end. A surprising amount of variation in wind direction was observed, and in many instances it was difficult to estimate the average direction.

At the completion of each test the quantity of water caught in each receptacle was determined. In the case of the rain gages this was done with the usual measuring stick, which gave the quantity as inches in depth over the area of the top of the gage. In the case of the cans the water was measured in a measuring glass and the quantity subsequently reduced to inches in depth over the area of the top of the can by multiplying by a suitable factor. Although two diameters of the top of each can were carefully measured, the difference between cans was found to be inconsequential from the standpoint of these tests, and the conversion of the quantity of water caught in the respective tests from milliliters to inches in depth was made in all cases by multiplying by the factor 0.0023.

Each sprinkling device was given at least two tests, and more if conditions warranted. These tests were normally made at substantially the higher and the lower of the pressure limits recommended by the manufacturer. If the range was great, an extra test at about the mean of the two was made, and for various reasons certain additional tests were made. From the data thus obtained some representative tests are presented in the form of distribution diagrams. These distribution diagrams take the form of contour maps of water depth. Where the contour lines are widely separated uniformity of distribution is, of course, indicated. The figures shown on the contours are hundredths of an inch depth in half an hour.

Owing to the readiness with which injury may be done to some plants by too much as well as by too little water, it is believed that to be thoroughly satisfactory a sprinkler should deposit over no considerable area more than twice as much water as it deposits in the area receiving the least water.

Water was brought to the edge of the field in a standard 3-inch iron pipe equipped with a cut-off valve. A large elevated water tank provided a pressure of about 40 pounds per square inch. Higher pressures, up to about 58 pounds per square inch, could be obtained by means of pumps. On the discharge side of the cut-off valve a standard 2-inch water meter was installed. From the meter the piping arrangement varied according to the sprinkler being tested.

For the tests made of two nozzles in the spring of 1931 a different testing area was used, where it is believed the wind effects were minimized. This plot had a much more level surface, and no effort was made to bring the tops of all the cans to the same level. The cans were placed at 5-foot intervals on the lines passing through the nozzle as a center, the nozzle itself dividing one of the 5-foot intervals. The convergence at the nozzle of these diametral lines resulted in a concentration of cans near the nozzle and for that reason certain cans were generally omitted when regular spacing along the line brought a spacing much closer than 5 feet.

For the tests of these two nozzles a 1½-inch supply pipe brought the water to the base of the nozzle. A new 1-inch water meter was used, and the Biram-type anemometer was not mounted on a swinging vane but set on a suitable support at a height of about 3 feet

above the ground and faced into the wind as closely as possible, to determine its direction. Otherwise the tests made in 1931 differed in no important particular from those made in 1928.

SETTING UP THE APPARATUS

The greatest differences in the set-ups of the individual nozzles were due to the necessity of installing a gauge to determine the pressure of the water. In the case of the sprinkler designed for installation at the top of a riser pipe, a 40-foot length of $\frac{1}{2}$ -inch pipe supported by stakes about 3 feet above the ground and having a pressure gauge at one end was attached to the riser at the base of the sprinkler as shown in Figure 3.

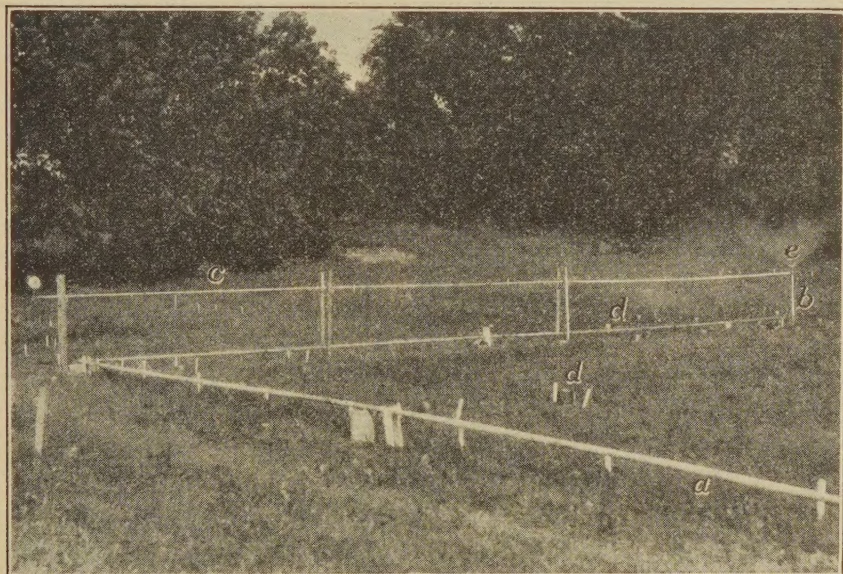


FIGURE 3.—General arrangement used for riser mounting: *a*, Supply pipe; *b*, riser pipe; *c*, long gauge pipe; *d*, some of the catching receptacles; *e*, a small stationary nozzle in operation.

Where sprinklers were arranged for hose connection the riser pipe was lowered to about 2 inches, and the gauge pipe taken back from that elevation. The top of the riser pipe tee was plugged, and a hose coupling screwed into the outer end of the run of the tee fitting at the end of the supply pipe. The sprinkler was then attached to the hose coupling, and in each test the pipes were moved about until the nozzle was properly located with respect to the catchment-receptacle arrangement.

TESTS OF REVOLVING-TYPE SPRINKLERS

WESTERN ORCHARD SPRINKLERS

Four different types of sprinklers were tested that have been rather widely used in orchard irrigation in California. These sprinklers are shown in Figures 4, 6, 8, and 10.

WATER-WHEEL TYPE OF SPRINKLER

One of these sprinklers (fig. 4) discharges its water through two orifices—one large and one small. The main function of the small stream is to operate a small water wheel, although it does irrigate the ground immediately around the riser pipe. This water wheel is connected with the body of the sprinkler through a chain of worms and gears, so that when the water wheel revolves the main body of the sprinkler, including the large orifice, is caused to rotate about the vertical axis, thus distributing the water over a considerable area. The particular sprinkler tested is designed to irrigate a circle 92 feet in diameter under a water pressure of 30 pounds per square inch, thus discharging 12 gallons per minute. The distribution diagrams

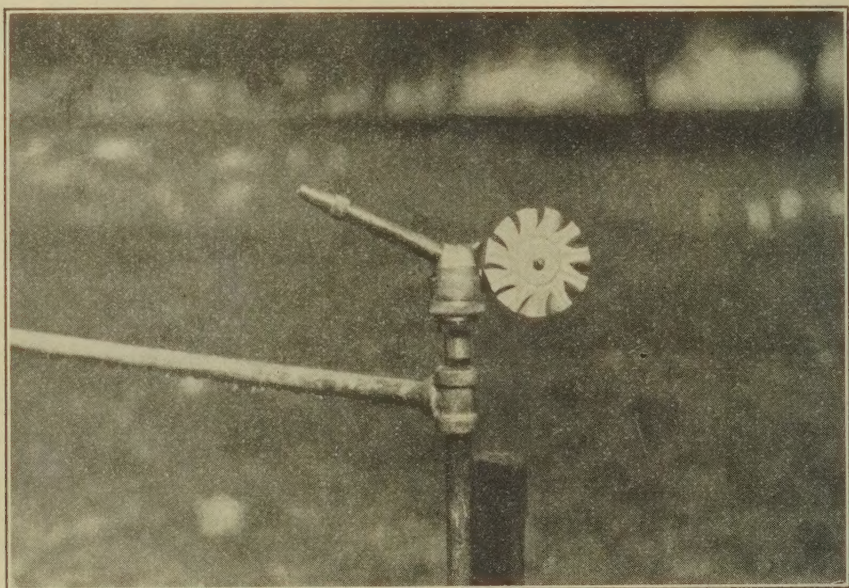


FIGURE 4.—Water-wheel type of sprinkler

(fig. 5) indicate that only the outer fringe of the wetted area received insufficient water while by far the greater part was thoroughly watered.

The manufacturer furnishes this sprinkler threaded for connection to a $\frac{1}{2}$ -inch riser pipe, whereas a larger riser is much to be preferred. This is particularly unfortunate because the difference in performance is not noticeable to the eye. In the tests in which a riser pipe 35 inches high was used between the supply pipe and the point of gauging, the pressure on the sprinkler was increased 2 pounds per square inch by reaming the ends of the $\frac{1}{2}$ -inch riser pipe which was first installed. By replacing the $\frac{1}{2}$ -inch riser pipe by a $\frac{3}{4}$ -inch pipe of the same length, a further increase of 2 pounds per square inch on the sprinkler was obtained, and by reaming the ends of the $\frac{3}{4}$ -inch pipe a still further increase of 1 pound per square inch was obtained. Thus an increase of 5 pounds per square inch in the pressure on the nozzle was obtained by substituting a 35-inch length of $\frac{3}{4}$ -inch pipe with reamed ends for a 35-inch length of $\frac{1}{2}$ -inch pipe with the ends

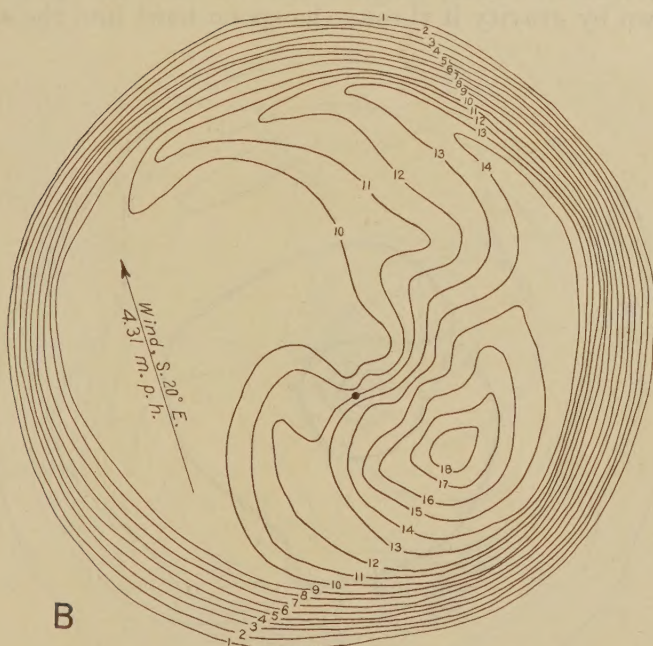
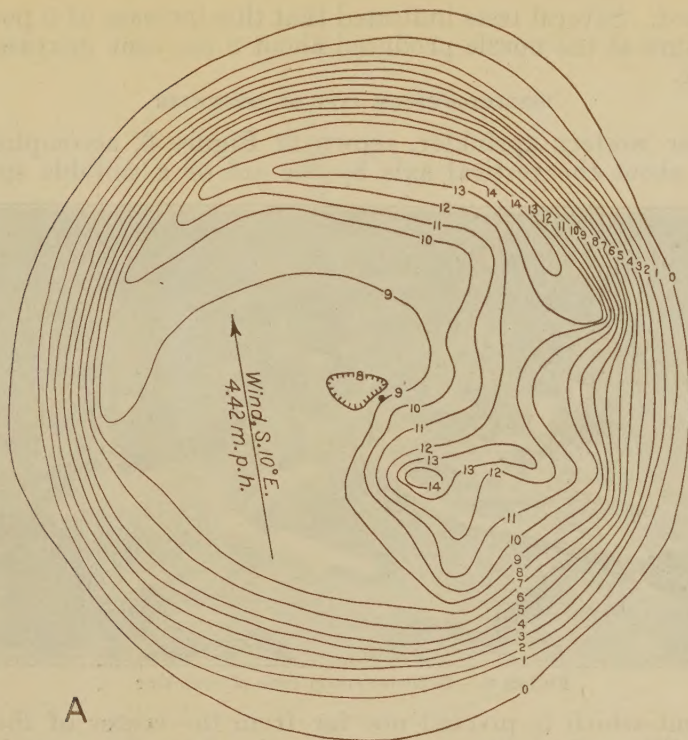


FIGURE 5.—Distribution under water-wheel type of sprinkler:
 A, Pressure, 25.7 pounds per square inch; water discharged, 10.58 gallons per minute. B, Pressure, 31.9 pounds per square inch; water discharged, 11.70 gallons per minute

not reamed. Several tests indicated that this increase of 5 pounds in the pressure at the nozzle produced about 9 per cent increase in the discharge.

DEFLECTOR-SPOON TYPE OF SPRINKLER

Another western sprinkler, shown in Figure 6, accomplishes its rotation about the vertical axis by the aid of a suitable spoonlike

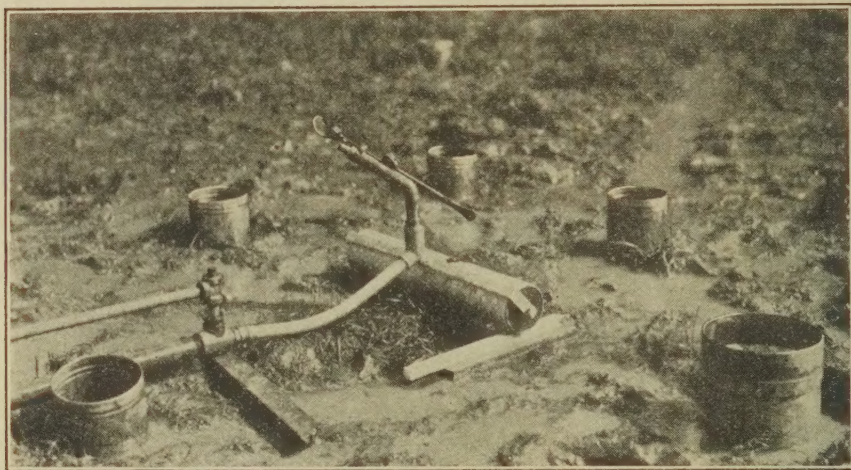


FIGURE 6.—Deflector-spoon type of sprinkler

attachment which is pivoted not far from the center of the spoon handle. When the latter, which is heavier than the spoon bowl, is drawn down by gravity it throws the spoon bowl into the stream of

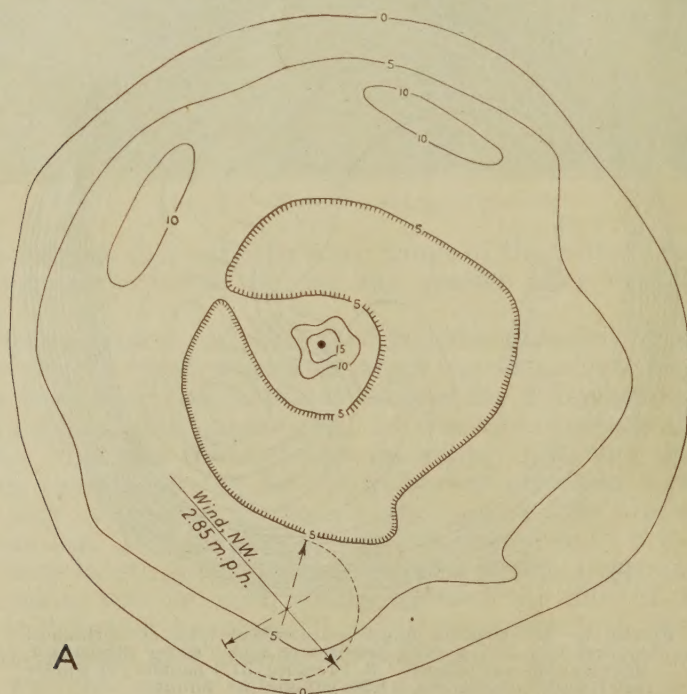


FIGURE 7.—Distribution under deflector-spoon type of sprinkler:
A, Pressure, 25 pounds per square inch; water discharged, 9.92 gallons per minute

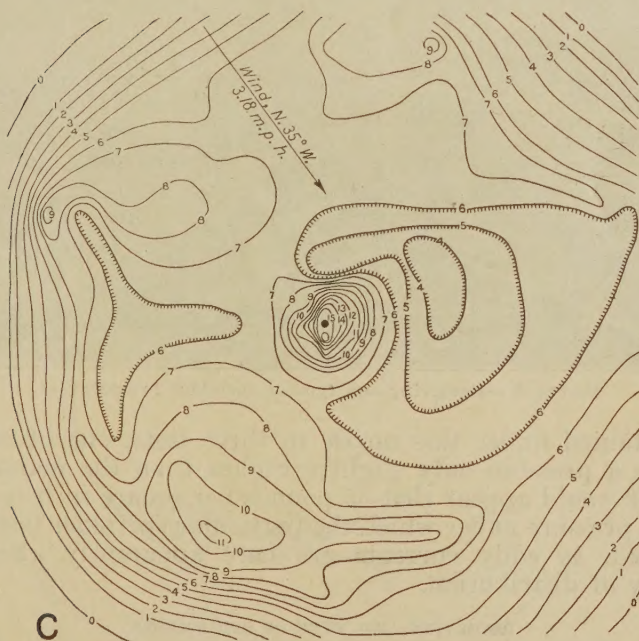
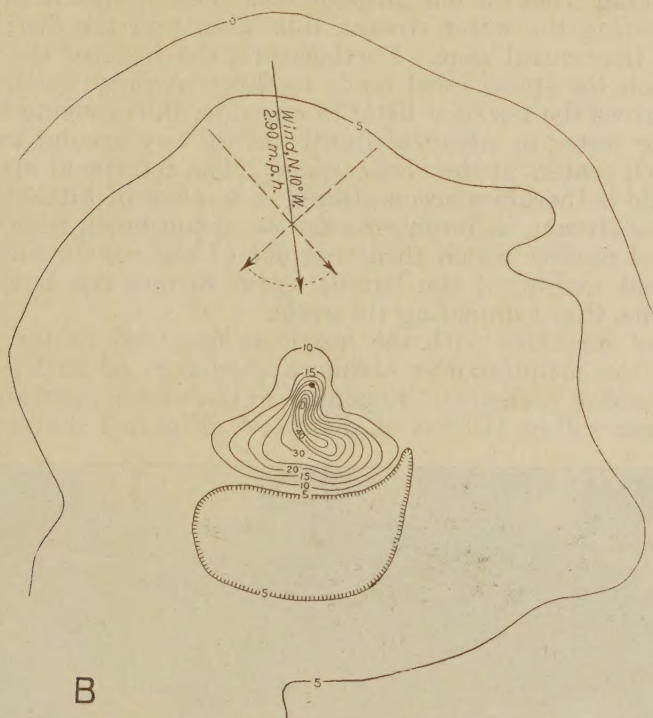


FIGURE 7.—Distribution under deflector-spoon type of sprinkler—
Continued.—B, Pressure, 42 pounds per square inch; water dis-
charged, 13.72 gallons per minute; C, Pressure 55 pounds per
square inch; water discharged, 15.38 gallons per minute

water issuing from the one large orifice. This results in breaking up and deflecting the water stream, thus aiding in the distribution of water in the central zone. Furthermore, the force of the water impinging on the spoon bowl tends to throw it downward, and in so doing throws the nozzle a little to one side, thus causing the stream of issuing water to advance slightly in its way around the circular area which centers at the vertical axis. The rotational movement of this nozzle is therefore accomplished in a series of hitches or jumps. The water stream, in impinging on the spoon bowl, imparts to it a downward motion which throws it out of the stream line until the unbalanced weight of the handle again throws the bowl into the stream line, thus completing the cycle.

For the sprinkler with the nozzle orifice used in the tests here reported the manufacturer claims a discharge of 15.2 gallons per minute under a pressure of 40 pounds to the square inch, and that the wetted area will be 110 feet in diameter. Figure 7 shows the distri-

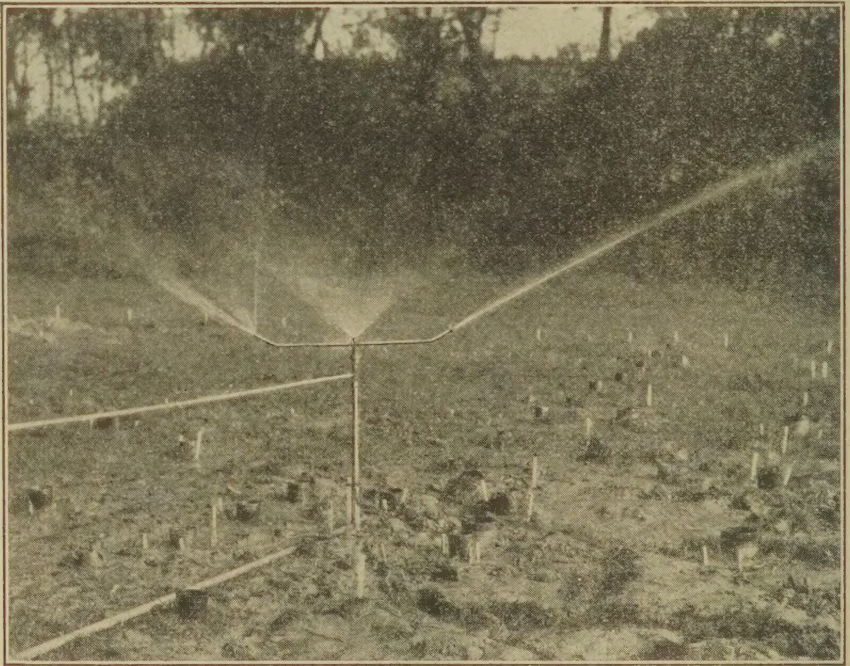


FIGURE 8.—Revolving-arm type of sprinkler in operation

bution obtained under this nozzle in three tests, one of which was run under a pressure only slightly higher than the manufacturer's rating. It would appear that 55 pounds per square inch is about the maximum pressure under which the particular sprinkler tested should be operated, as eddy currents are here apparently affecting the uniformity of distribution.

REVOLVING-ARM TYPE OF SPRINKLERS

The third western orchard sprinkler, shown in Figure 8, is one of the revolving-arm type. This sprinkler is rotated by the force of the discharging water without the aid of gearing or other mechanical devices. The one tested here was equipped with a small center nozzle

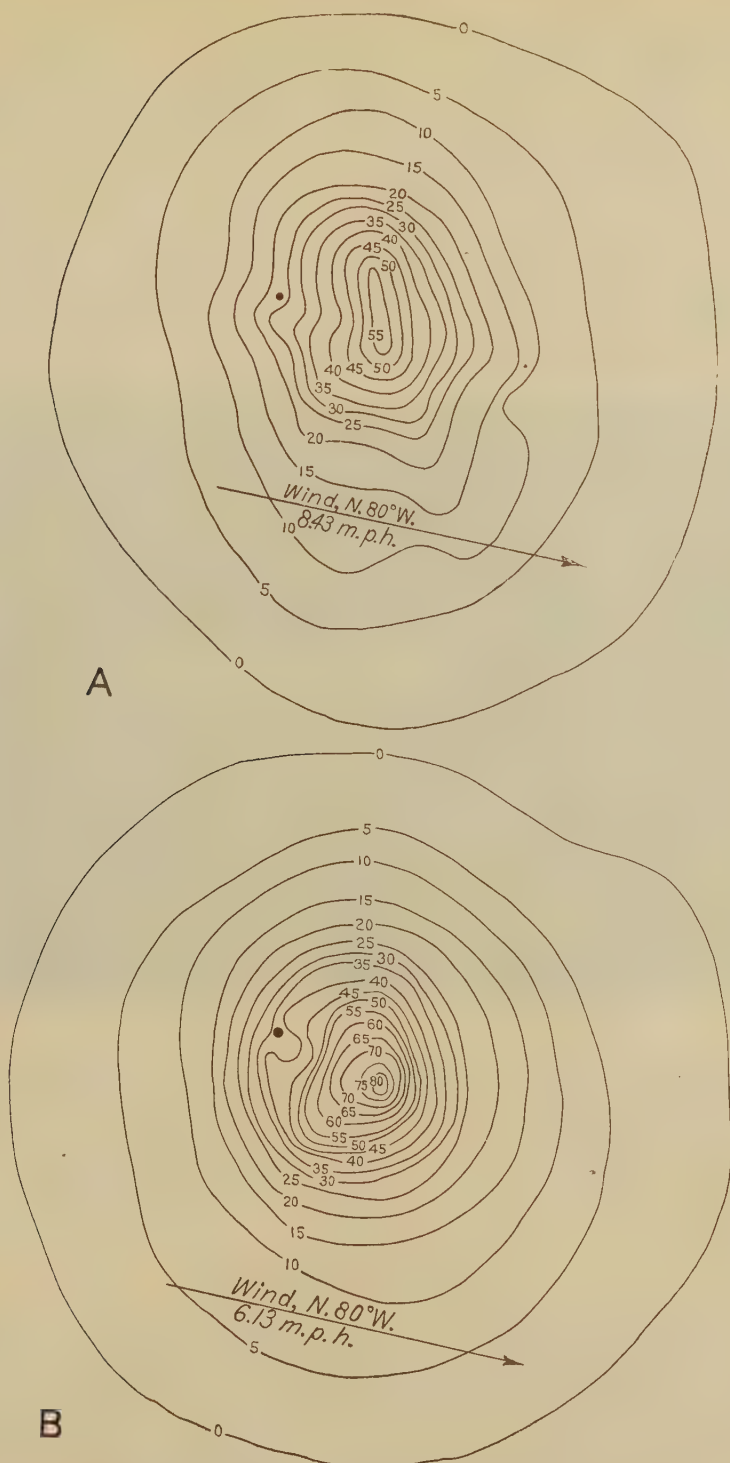


FIGURE 9.—Distribution under revolving-arm sprinkler shown in Figure 8: A, Pressure, 25 pounds per square inch; water discharged, 8.66 gallons per minute. B, Pressure, 40.4 pounds per square inch; water discharged, 11.25 gallons per minute

which, by an action equivalent to that of deflection vanes, also aids rotation slightly. For these tests the sprinkler was equipped as obtained from the manufacturer with the central nozzle above mentioned, and also with a slotted nozzle on the end of one revolving arm and a rifled nozzle on the other. The distribution diagrams shown in Figure 9 were obtained when this nozzle thus equipped was used.

The fourth sprinkler, here classed as a western orchard sprinkler, has been thus classified because of the extent of its use in that field. It is one of the two nozzles tested in 1931 and is shown in Figure 10. The large arm is caused to rotate by the force of the water discharging through the nozzle, which is directed to one side. The small arm, suitably pivoted on the short end of the large arm, is likewise given

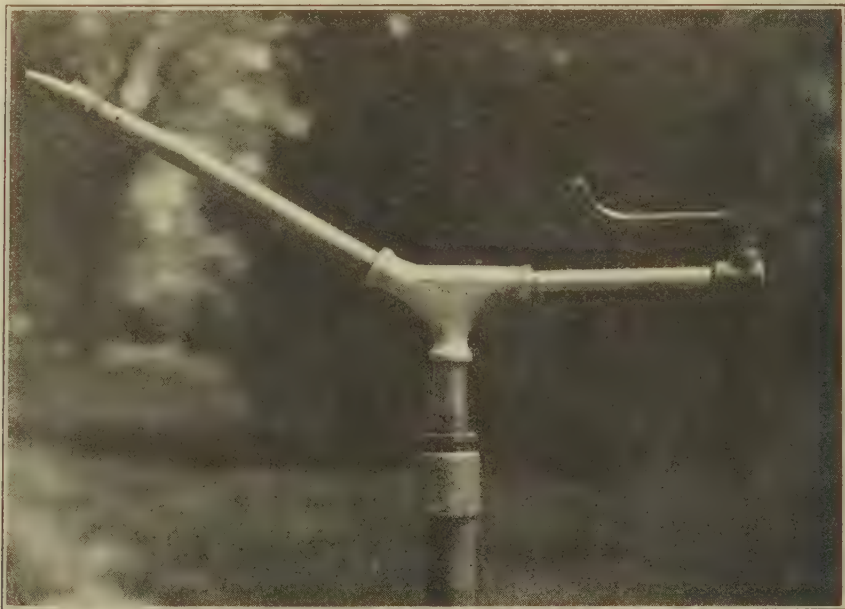
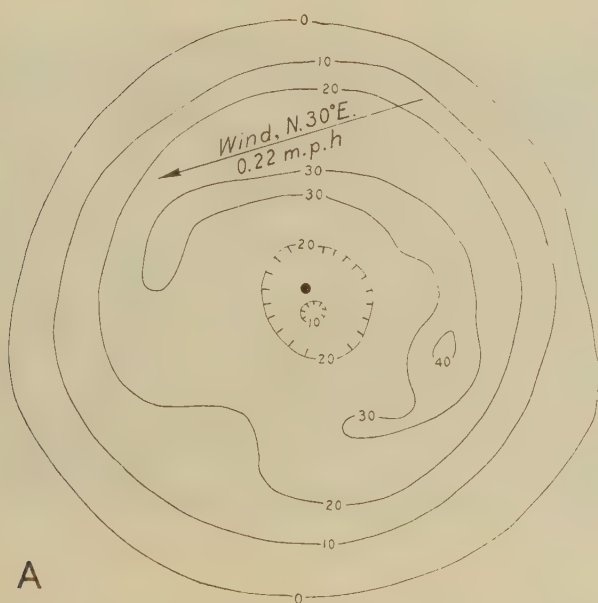


FIGURE 10.—Another revolving type of sprinkler

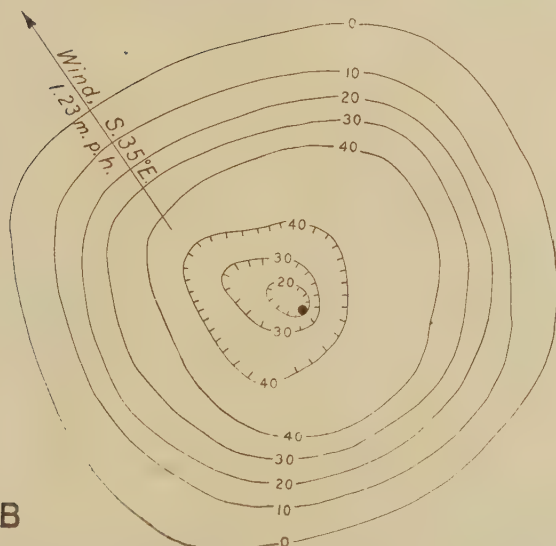
an independent rotary motion by the force of a small stream of water which is discharged by its small nozzle and also directed to one side. This small nozzle serves to water the area immediately around the riser that supports the whole device. These tests were made around the higher of the pressures recommended by the manufacturer. The distribution diagrams shown in Figure 11 were obtained under this nozzle.

OTHER AMERICAN SPRINKLERS

Examples of another group of sprinklers tested are shown in Figures 12, 14, and 16. This group includes a large number of sprayers manufactured by many different concerns. From among the many possibilities three outfits were chosen for the purposes of this test. One of these is marketed as an inexpensive sprayer, and one is rather high priced. All three obtain rotation from the propelling power of the jets of water issuing from the sides or ends of the nozzle arms.



A



B

FIGURE 11.—Distribution under revolving-arm sprinkler shown in Figure 10: A, Pressure, 40 pounds per square inch; water discharged, 14.77 gallons per minute. B, Pressure, 55 pounds per square inch; water discharged, 16.69 gallons per minute

The inexpensive nozzle shown in Figure 12 has a single small orifice in the end and three smaller orifices in the sides of each of the three revolving arms, which are all of the same size and length.

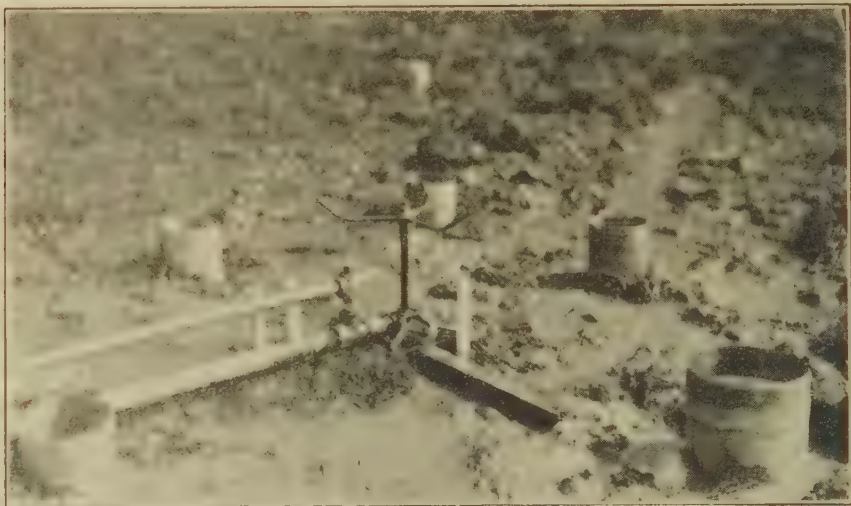


FIGURE 12.—Inexpensive sprinkler of the revolving-arm type

Figure 13 indicates the distribution as found in two tests. No statement of manufacturers' claim is available.

The medium-priced sprinkler of this same type (fig. 14) has several small holes in the ends of each of the four arms, two of which

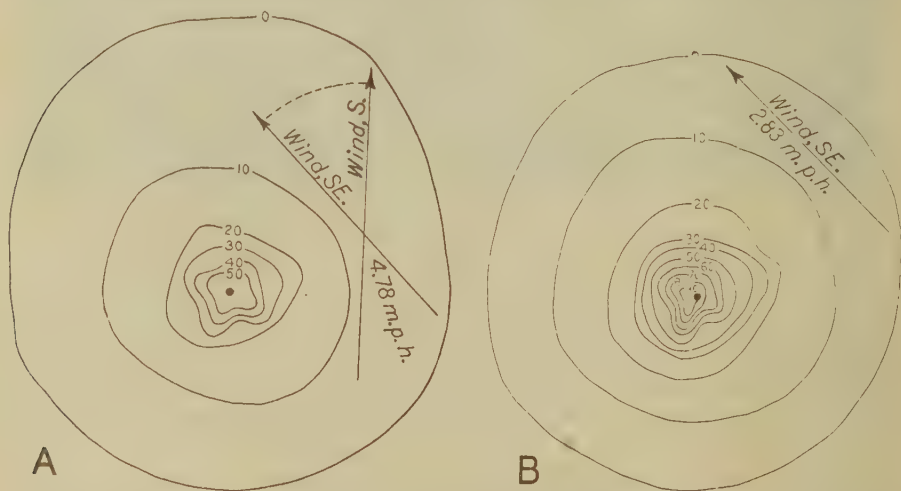


FIGURE 13.—Distribution under revolving-arm sprinkler shown in Figure 12: A, Pressure, 29 pounds per square inch; water discharged was below proper range of meter. B, Pressure, 41 pounds per square inch; water discharged was below proper range of meter.

are about one-half as long as the other two. This sprinkler when in operation gives a spray that is rather pleasing to the eye. Distribution diagrams shown in Figure 15 were obtained from this sprinkler.

The third and most expensive sprinkler of this group (fig. 16) discharges its water from a special adjustable nozzle at the end of each arm. The adjustment is accomplished by turning a thumb nut at the back of the nozzle, which moves an interior deflector forward or backward. The distribution range of this sprinkler depends to a large



FIGURE 14.—Revolving-arm sprinkler of medium price

extent on the nozzle adjustment, as is shown by the two distribution diagrams (fig. 17), a greater range having been obtained by careful adjustment at a low pressure than was obtained at a higher pressure when adjusted for a spray more pleasing to the eye.

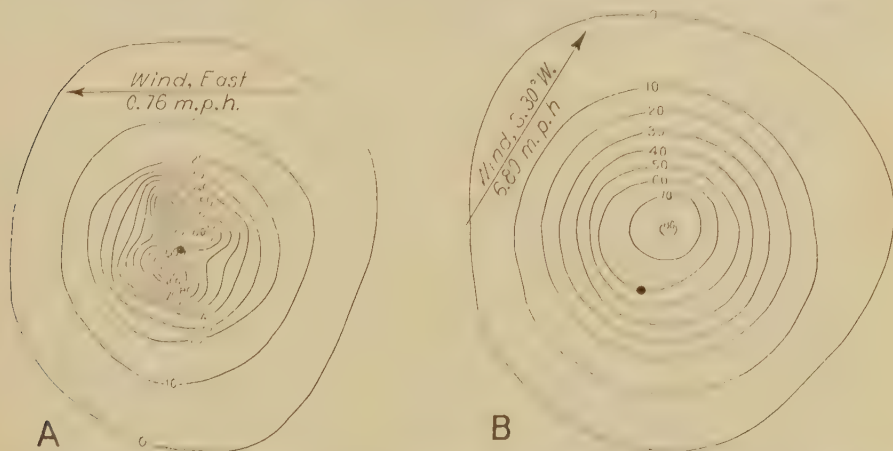


FIGURE 15.—Distribution under revolving-arm sprinkler shown in Figure 14: A, Pressure 24 pounds per square inch; water discharged was below proper range of meter, B, Pressure, 58 pounds per square inch; water discharged, 6.64 gallons per minute

It would appear that better distribution will be necessary to render the revolving-arm sprinklers of greatest value in the irrigation of delicate vegetable crops.

Two small-range stationary nozzles were tested; one was a fixed or nonadjustable type, while the other was adjustable. Figure 18 shows the performance of the fixed type nozzle.

The adjustable nozzle was essentially a cone-shaped plug of such a size that when brought up close to the end of the short brass-pipe nipple that comprised the rest of the nozzle it would partially plug



FIGURE 16.—Revolving-arm sprinkler having an adjustable nozzle at the end of each arm

the opening. The cone-shaped plug was attached at its apex to a small threaded brass rod which extended into the hollow center of the brass-pipe nipple far enough to pass through a threaded nut fastened within the nipple by three small radial ribs. The best

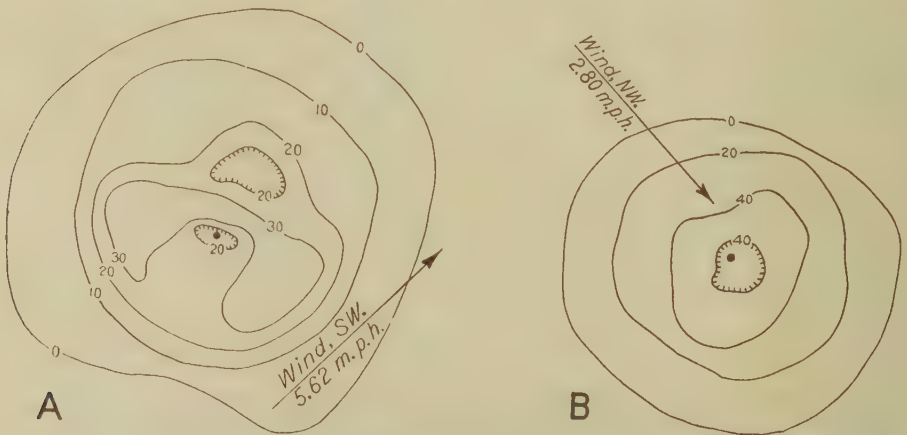


FIGURE 17.—Distribution under revolving-arm sprinkler shown in Figure 16: A, Pressure, 10 pounds per square inch; water discharged was below proper range of meter. B, Pressure, 44 pounds per square inch; water discharged, 4.95 gallons per minute

results were obtained by having the plug opened to the extent of one-half or three-fourths of a turn. Figure 19 shows two examples of the performance of this nozzle. This nozzle was one of the two tested in 1931.

The sprinklers so far discussed have been of American manufacture and all designed to wet a circular area. It is evident that such nozzles, no matter how successfully they may distribute water over

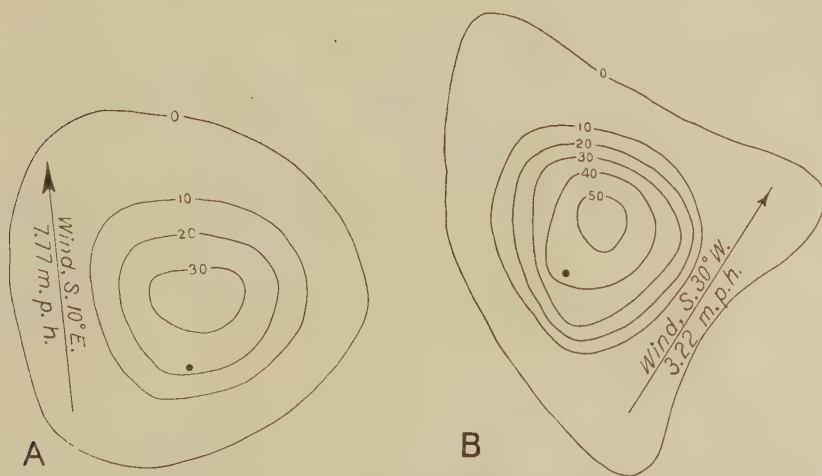


FIGURE 18.—Distribution under stationary sprinkler: A, Pressure, 26 pounds per square inch; water discharged, was below proper range of meter. B, Pressure, 40 pounds per square inch; water discharged, was below proper range of meter

a circular area, leave much to be desired, because if circles just touch one another a considerable area is left unwatered, and if they overlap a great amount of double coverage results.

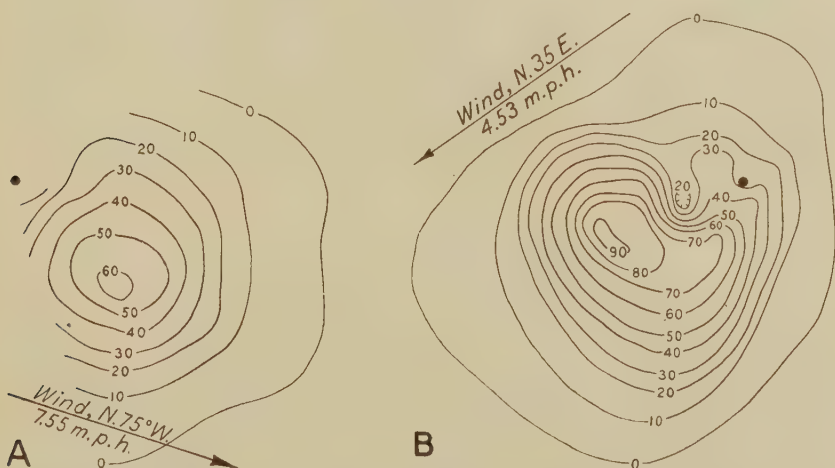


FIGURE 19.—Distribution under stationary sprinkler with adjustable discharge opening: A, One-half turn open; pressure, 30 pounds per square inch; water discharged, 6.03 gallons per minute. B, Three-fourths turn open; pressure, 50 pounds per square inch; water discharged, 12.41 gallons per minute

GERMAN SQUARE-AREA SPRINKLERS

To overcome the objections to circular distribution various German manufacturers have developed outfits for spraying water over a square area. Two sprinklers from among the outfits on the market

were selected for testing; both were chosen from the output of one manufacturer in order to have nozzles which would fit the one set of special pipe that was obtained. This equipment is intended to be portable, and its advantage as cheap irrigating equipment depends upon this feature. For this reason the pipes are equipped with a quick-acting joint device, and those that are expected to be moved most frequently are made of a very light metal, probably aluminum or an aluminum alloy. The pipes for mains and main laterals intended for less frequent moving are of iron.

In setting up a distribution line the pipes are assembled by simply shoving the end of one pipe into a special fitting fastened to the end of the adjoining pipe. A specially-shaped rubber gasket is depended on to make the joint water-tight. A spring catch, supplemented by a short chain at the end sprinkler, prevents the pipe from blowing out when subjected to pressure. These joints proved very effective. The flexible gaskets require frequent renewal, but the expense of the replacement should not be great.

Various features of the design and construction of the apparatus appear in Figure 20. Sprinklers or junction fittings for taking off branch lines may be set into the top openings of the connecting pieces by pulling out the caps normally used to plug the upper openings. To connect this German equipment with standard American pipe a special fitting was made by welding a short length of the 82-millimeter (3¼-inch) German iron pipe to a 6-inch nipple of 3-inch standard American pipe.

As before stated, two types of spraying nozzles were tested. One is of the stationary type with many small holes, designed to spray a relatively small area. The particular one tested is supposed to spray uniformly a square area 12 meters (about 40 feet) on a side. It is equipped with a small removable screen to keep trash carried by the water from clogging the small holes. This sprinkling device is shown in operation in Figure 20, C.

For testing this sprinkler the receptacles for catching the spray were arranged as shown in Figure 1. The tests were continued for 60 minutes, but for purposes of comparison the resulting distributions as shown in Figure 21 are reduced to the 30-minute equivalent.

The gauge pressures shown for these two tests are the readings as obtained at the junction fitting on the main pipe line substantially 40 feet from the nozzle. No correction was made for friction in this 40 feet of 3-inch pipe, since this would be quite small. Considered from any standpoint, the distribution is unsatisfactory, since a considerable portion will receive more than twice as much water as will that part of the area that receives the least quantity.

The larger German sprinkler is of the revolving type and is equipped with two discharge openings. One of these, relatively small, is shaped to operate as a jet-propulsion nozzle and by its rotation drive suitable gears which cause the body of the sprinkler to revolve. At the same time, by means of a cam motion, it partly opens and closes the larger outlet and also by that means deflects upward and downward the stream emitted. In this manner the stream of water is shortened and lengthened four times for every revolution of the nozzle, in an effort to spray the water over a square area. The manufacturers claim that this sprinkler shown in Figure

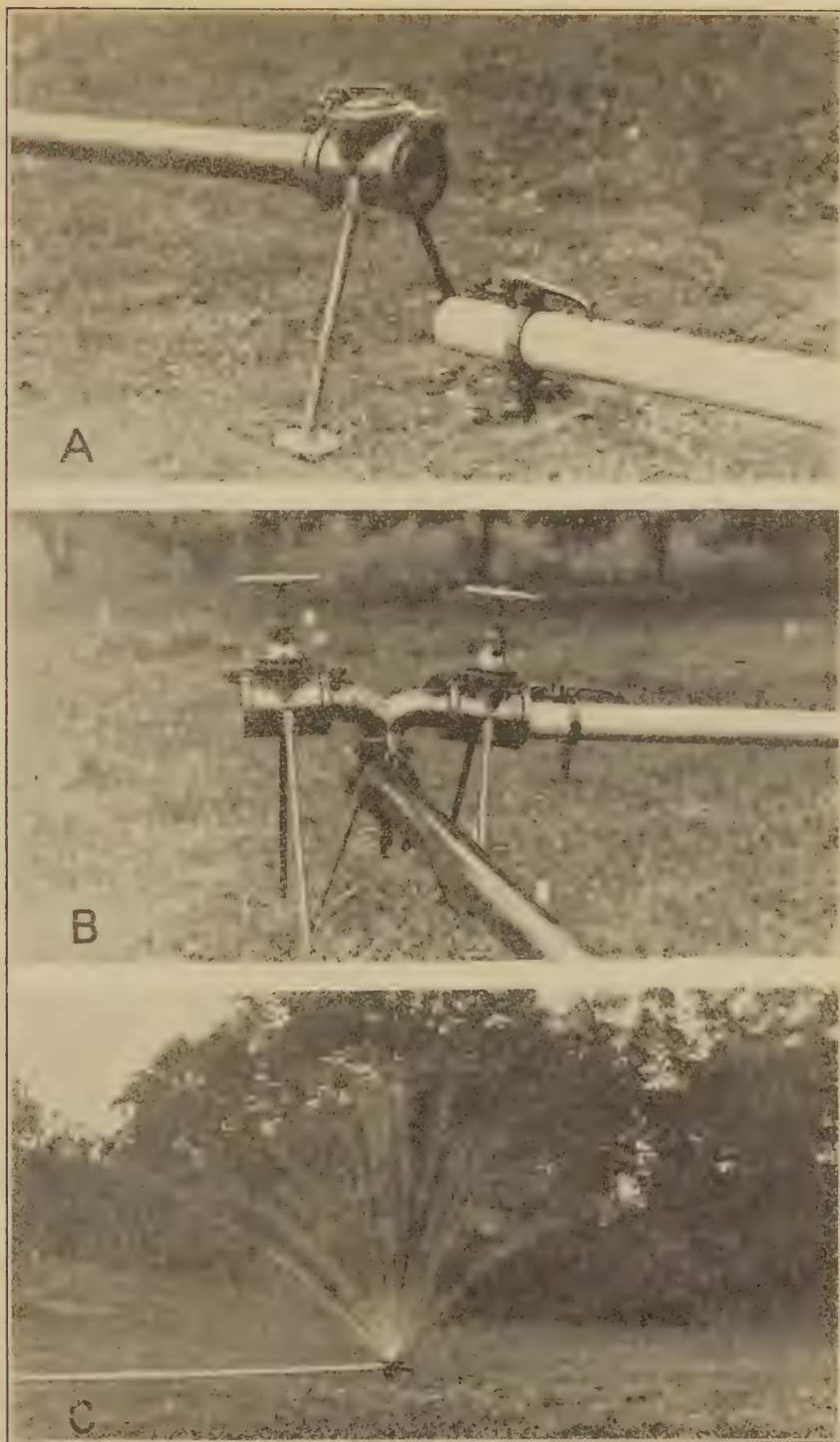


FIGURE 20.—German spray-irrigation equipment: A, Quick-acting coupling with the pipe disassembled; B, fitting used to take off a branch pipe line; C, small nozzle in operation which is designed to irrigate an area 12 meters (about 40 feet) square

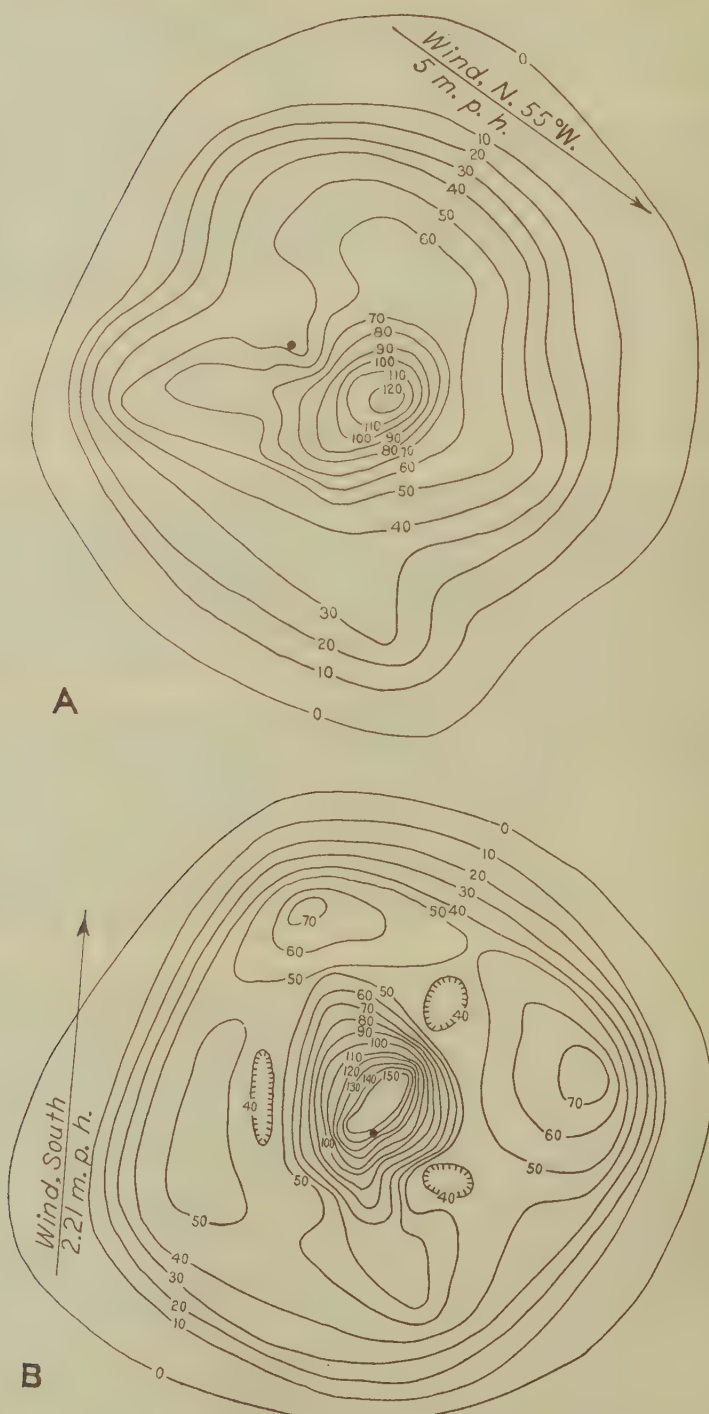


FIGURE 21.—Distribution under small square-spray nozzle: A, Pressure, 23 pounds per square inch; water discharged 22.68 gallons per minute. B, Pressure, 22 pounds per square inch; water discharged, 25.15 gallons per minute

22 will irrigate a square 120 feet on a side under a pressure of from 3 to 3.5 atmospheres (44 to 52 pounds per square inch). For these tests the water receivers were arranged as shown in Figure 1. The distribution (fig. 23) again is shown to be very poor. A considerable part received more than twice the depth of water that fell on the part that received the minimum wetting.

OVERHEAD-PIPE SYSTEM

Tests were made to determine the character of distribution obtained with the overhead-pipe system so commonly used in the United States for the irrigation of vegetables. The basic unit of



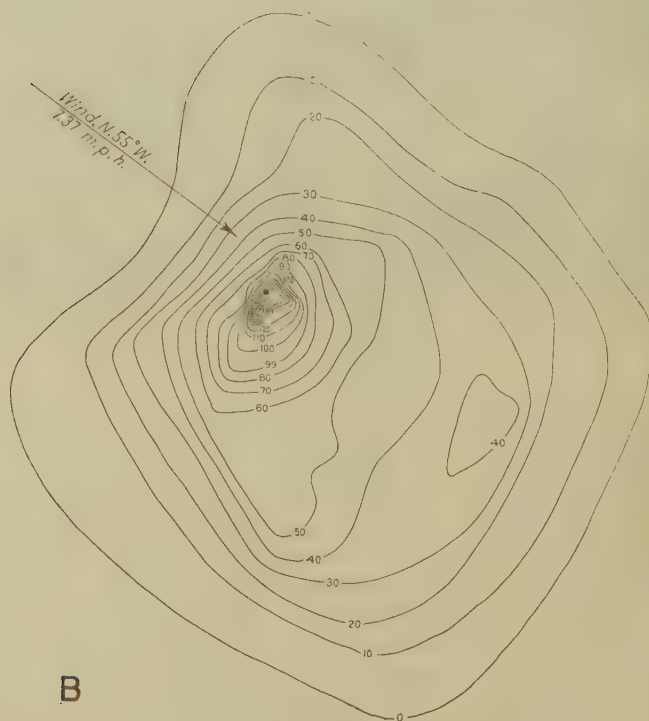
FIGURE 22.—German spray-irrigation equipment. Close-up view of sprinkler designed to irrigate an area 120 feet square

this system, an overhead pipe with many small nozzles, irrigates a rectangular area. The nozzles, which have very small apertures, are inserted in specially drilled and tapped holes located longitudinally along the pipe. By rotating the pipe the nozzles wet an area about 50 feet wide, that is, 25 feet on either side of the pipe.

For these tests an overhead-pipe spray line about 89 feet long was constructed. This consisted of four 20-foot lengths of spray-nozzle pipe and three 3-foot separator pipes. Each length of spray-nozzle pipe was fitted with nozzles from a different manufacturer; thus four different types of nozzles were under examination during each test. The first 20-foot length of spray-nozzle pipe was 1 inch in diameter, the remainder of the line being of the $\frac{3}{4}$ -inch size. The catching receptacles were arranged as shown in Figure 2. For rotating the nozzle pipe line one or the other of two different types of automatic line turners shown in Figures 24 and 25 was used.



A



B

FIGURE 23.—Distribution under large square-spray nozzle: A, Pressure, 29 pounds per square inch; water discharged, 28.12 gallons per minute. B, Pressure, 53.7 pounds per square inch; water discharged, 39.70 gallons per minute



FIGURE 24. Automatic line turner for overhead pipe systems in operation



FIGURE 25.—Overhead-pipe system equipped with a type of automatic line turner different from that shown in Figure 24

Both of these proved to be very satisfactory in operation. In Figure 26 are shown the distribution diagrams obtained in these tests. The four different makes of nozzles tested are shown in Figure 27.

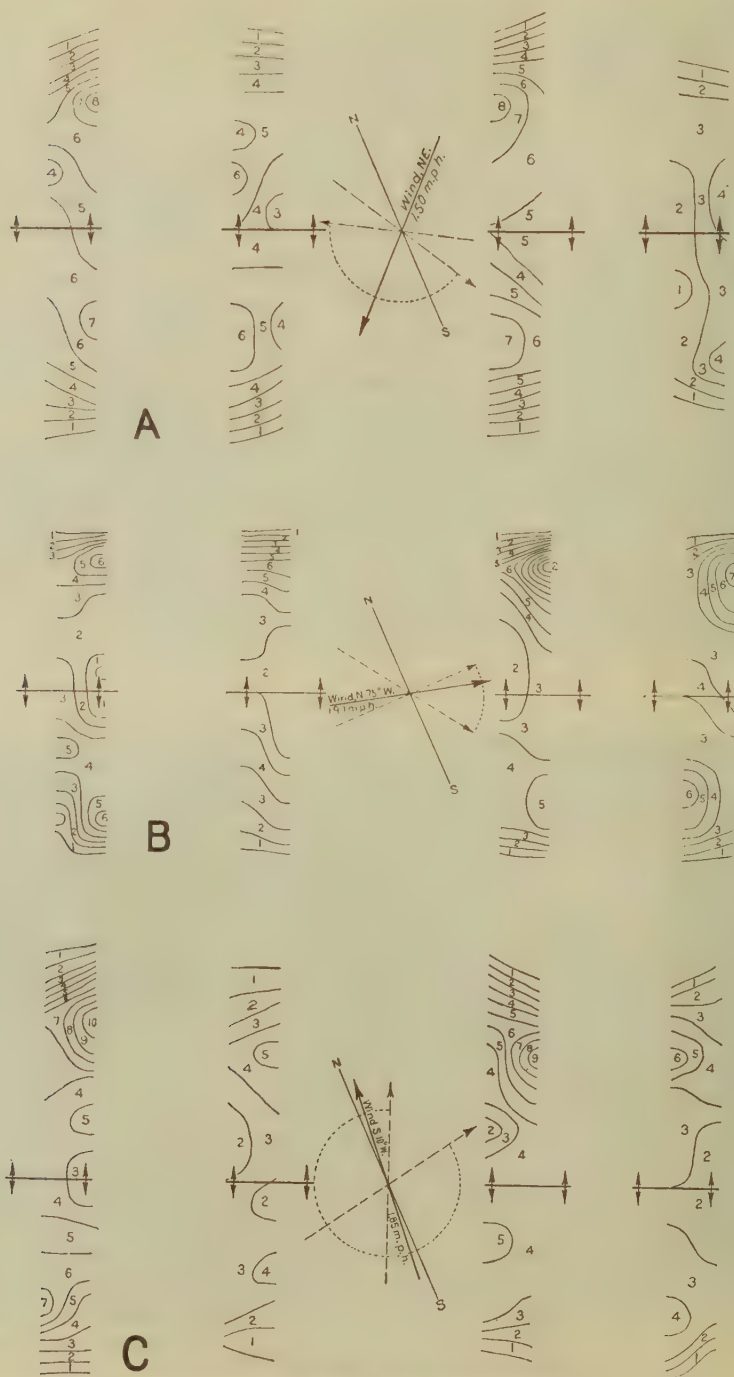


FIGURE 26.—Distribution under the overhead-pipe system : A, Pressure, 26 pounds per square inch; rotation angle, 90° ; time of one cycle, 1 minute 4 seconds. B, Pressure, 9 pounds per square inch; rotation angle, 130° ; time of one cycle, 3 minutes 12 seconds. C, Pressure, 17 pounds per square inch; rotation angle, 130° ; time of one cycle, 1 minute 37 seconds

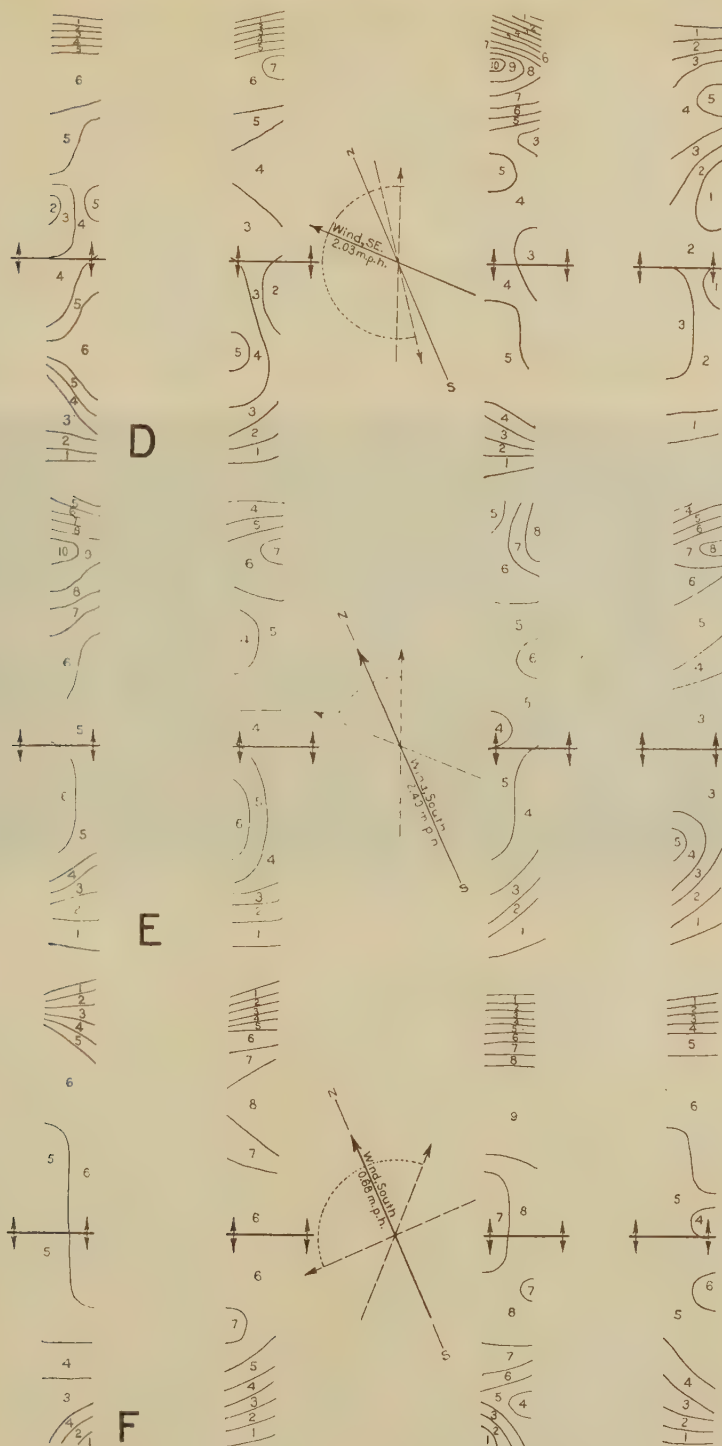


FIGURE 26.—Distribution under the overhead-pipe system—Continued.—
 D, Pressure, 26 pounds per square inch; rotation angle, 130° ; time of one cycle, 1 minute 25 seconds. E, Pressure, 39 pounds per square inch; rotation angle, 130° ; time of one cycle, 1 minute 8 seconds. F, Pressure, 56 pounds per square inch; rotation angle, 130° ; time of one cycle, 58 seconds

Nozzle *e* is the same as nozzle *d* except that a special screen has been added.

One of the most satisfactory distribution diagrams obtained is that in Figure 26 A, which shows the distribution curves as obtained from four different types of nozzles operating simultaneously. The experiments seemed to indicate that the greater wind velocities give the more uniform distribution. Practically, however, there is a serious difficulty in attempting this type of irrigation on small areas in high winds, namely, that a wide strip on the windward side of the field gets no water. Likewise there may be a harmful wetting of the land outside the field. Sometimes, where conditions are favorable as far as the above objections are concerned, it is possible to get excellent distribution from a system of parallel overhead nozzle

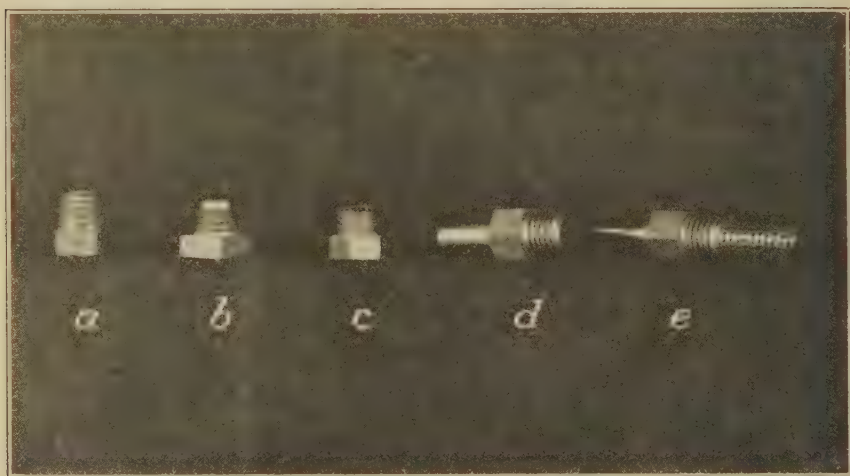


FIGURE 27.—Nozzles for overhead-pipe spray systems

pipes with a high wind from a direction perpendicular to those pipes, by pointing the nozzles upward and counting on the wind to do the entire work of distributing the water.

In judging the comparative distribution accomplished by these four types of nozzles a determination was first made of the width of the zone under each type that was fairly well wetted. In making this determination a narrow strip along the outer edges which received markedly less water than the rest normally was discarded because it obviously was too far from the nozzles themselves to come within their proper spraying range. With the width of the wetted zone established, the quantities of water caught in the individual containers within that area were compared. If no catchment within the area exceeded twice the minimum quantity caught the distribution was considered "very good." If one container (but only one) caught more than twice the minimum quantity deposited in any of the other receptacles the distribution was classed as "good," as was also the case if a single container caught less than one-half of the maximum quantity obtained within the zone. Below these two grades the distribution was classed as "fair" or "poor," on the basis of the general appearance of the distribution diagram but without any rigorous standard of comparison. On this basis the performances of the noz-

zles are compared in Table 2, the data being arranged in the order of increasing operating pressures.

TABLE 2.—*Distribution of four spray nozzles compared on the basis of pressure*

Test pressure	Angle of rotation	Distribution of—									
		Wind		Nozzle a		Nozzle b		Nozzle c		Nozzle d	
		Direction	Velocity	Width wet	Rating ¹	Width wet	Rating ¹	Width wet	Rating ¹	Width wet	Rating ¹
Pounds per square inch	Degrees		Miles per hour	Feet		Feet		Feet		Feet	
9	130	N. 75° W.	1.99	40	P.	40	F.	40	P.	40	G.
17	130	S. 10° W.	1.85	55	F.	45	G.	50	F.	50	G.
24	125	(?)	1.30	70	P.	70	P.	70	P.	60	P.
25	60	SE.	.30	³ 49	G. ³	40	G.	45	F.	40	P.
26	60	N. 10° E.	2.51	35	G.	35	V. G.	35	V. G.	35	V. G.
26	90	NE.	1.50	45	G.	50	V. G.	50	G.	40	V. G.
26	130	SE.	2.03	55	G.	55	F.	60	F.	50	P.
25	145	SE.	1.94	60	F.	55	F.	65	F.	55	P.
38	90	N. 70° W.	10.48	³ 45	V. G. ³	40	G.	45	V. G.	45	V. G.
39	105	S. 20° W.	8.55	50	G.	55	P.	50	F.	40	P.
39	130	S.	2.40	55	G.	55	V. G.	55	G.	55	F.
39	90	N. 60° W.	9.82	15	P.	45	V. G.	50	V. G.	³ 50	V. G. ³
39	105	NW.	8.56	³ 55	G. ³	55	G.	50	G.	55	V. G.
55	145	SE.	1.26	60	G.	60	G.	70	F.	³ 65	F. ³
56	130	S.	.68	55	V. G.	55	G.	55	G.	55	V. G.

¹ Distribution was rated as follows: Very good=V. G.; good=G.; fair=F.; poor=P.

² Wind was variable in direction and blew in gusts.

³ Estimated.

Table 2 shows that one type of nozzle was able to make good distribution under 9 pounds pressure, two types were able to do it under 17 pounds pressure, and all four could do it under 26 pounds pressure and again under 56 pounds. Intermediate results seem curiously spotted, due partly, it is believed, to the effect of wind.

The wide distribution but very poor showing made by all the nozzles in the test at 24 pounds pressure is undoubtedly due to the fitful wind. This wind blew in gusts and changed direction frequently, so that no estimate of average direction was possible. The low velocity figure given is of course due to the periods of calm between the gusts and the inertia of the weather vane and Biram type of anemometer when a fresh gust came from a new direction. In other words, it is believed that in an erratic wind such as prevailed during this experiment, the anemometer hardly began to register for a gust until it had nearly spent its force.

From the tests it is evident that if a pressure as high as 56 pounds per square inch is available, the nozzle lines may be spaced 55 feet apart where any of the common spray nozzles are to be used. For this condition a large angular rotation of the nozzle pipe should be used to get uniformity of distribution, if operated mechanically. This wide spacing of the nozzle lines, although requiring higher pressures, may reduce the initial investment for large spray systems.

If, however, a pressure of only 26 pounds per square inch is available in the water lines, the nozzle pipes should be nearer together, say 50 feet for nozzles *b* and *c*, 45 feet for nozzle *a*, and 40 feet for nozzle *d*. This may be accomplished with a 90° turning angle.

There seems to be little advantage in using a 60° angle as that would require closer spacing of the nozzle pipes with any of the nozzles.

With a turning angle of 130° it appears that one type of nozzle made a good showing under 9 pounds pressure, two under 17 pounds, three under 39 pounds, and all four under 56 pounds.

MEASUREMENTS OF NOZZLE DISCHARGE

Following the distribution tests a number of the individual nozzles from each manufacturer were tested to determine their discharge capacities under different pressures. These tests were made by catching in a 500-milliliter graduate glass the discharge from indi-

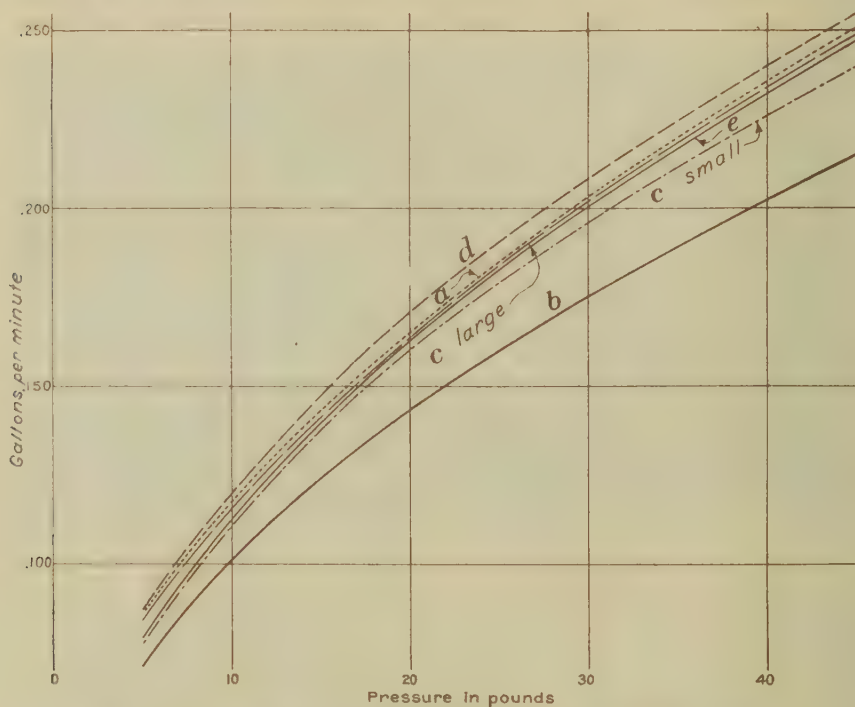


FIGURE 28.—Quantity of water discharged by overhead-spray nozzles

vidual nozzles when operating under certain pressures. By catching the discharges from the same nozzles when operating at different pressures and then repeating the performance with other nozzles of the same make and type, data were obtained for plotting a discharge curve for each make and type tested. In most cases the discharge from the individual nozzles of a type did not vary more than 5 per cent from the average for that type. In one instance this variation was greater than 10 per cent. Even for that type, however, it is not likely that the many nozzles used in an irrigation system would deviate greatly from the average quantity shown by its curve. The several curves of average discharges have been assembled in Figure 28. It will be noted that in general these nozzles have nearly the same capacity, one nozzle, however, discharging a quantity considerably below that handled by the others. The quantities given

in Figure 28 for the individual nozzles, when adjusted to the number of nozzles then operated, agree within 5 per cent with the quantities registered directly by a 1-inch water meter inserted in the supply line.

SUMMARY

These tests indicate that more uniform distribution over a large area can be obtained with the overhead-pipe system than with any other type of spray-irrigation equipment now available. This is because each unit wets an approximately rectangular area and when properly handled will wet it quite uniformly. Furthermore, the areas irrigated by adjacent units join without serious overlaps and without serious gaps.

Uniformity of distribution is very important for the irrigation of small plants, in order that all may have substantially similar growing conditions, maintain approximate uniformity of size, and be brought to maturity at the same time. Uniformity of distribution is also very important on any irrigated area that needs to be plowed or cultivated if the soil tends to become hard when dry. This is as true of an orchard as of a vegetable garden because plowing or cultivating is very unsatisfactory when varying hard and soft spots are encountered. The demand for uniform distribution of water is one reason for the widespread use of overhead-pipe systems for the irrigation of commercial vegetable gardens in spite of its very high cost.

The German idea of a sprinkler intended to wet a square area is not without merit. However, the two types of square spray nozzles tested came so far short of accomplishing this aim that their introduction into this country is not warranted.

The distribution made by two of the circular sprinklers was reasonably uniform but under most of them it was very poor. Lack of uniformity of distribution is especially unfortunate where the nozzles are to be operated from fixed risers because, as a rule, the spots that are overirrigated in one watering are likely to be overirrigated in all waterings and the spots that get but little water at one irrigation probably get but little in following irrigations. Further difficulties are encountered with this type of sprinkler owing to impossibility of so grouping these sprinklers as to avoid overlapping at some places and the occurrence of dry gaps at others. When used as portable sprinklers on the ends of flexible hose inequalities of distribution may be partly compensated by variations in placing from watering to watering.

It is believed that manufacturers should endeavor to develop better equipment for circular-spray irrigation.

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